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FLUTTER OF TWO PARALLEL FLAT PLATES CONNECTED LATERALLY BY AN ELASTIC MEDIUM

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INTRODUCTION

(NASA TMX 50984)

The flutter behavior of a structural configuration consisting of two rectangular, simply supported, parallel plates laterally connected by many closely spaced linear springs is investigated. The configuration analyzed is shown in figure 1. The upper plate has air flowing at supersonic speed over the upper surface and both plates are subjected to midplane loadings.

This configuration is an idealization of a micrometeoroid bumper which is attached to a primary structure by a light, soft, filler material. The aeroelastic behavior of such a configuration may be important in the design of structural components of a manned space station which are exposed to an airstream during launch.

SYMBOLS

$$A_{\pm} = R_{x\pm} - 2\left(\frac{a}{b}\right)^2$$

a,b   plate length and width, see figure 1

$$B_{\pm} = \frac{\Omega_{\pm}^2}{\pi^4} + \left(\frac{a}{b}\right)^2 R_{y\pm} - \left(\frac{a}{b}\right)^4$$

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$D_{\pm}$ plate flexural stiffness

$h_{\pm}$ thickness of plate

k elastic spring constant

l lateral aerodynamic load

M Mach number

$N_{x\pm}, N_{y\pm}$ midplane force intensities, positive in compression

q dynamic pressure, $\frac{\rho U^2}{2}$

$R_{x\pm} = \frac{a^2 N_{x\pm}}{\pi^2 D_{\pm}}$

$R_{y\pm} = \frac{a^2 N_{y\pm}}{\pi^2 D_{\pm}}$

$S_{\pm}$ spring stiffness parameter, $\frac{ka^4}{\pi^4 D_{\pm}}$

t time

U free-stream velocity

$w_{\pm}$ lateral deflection of plate

x,y Cartesian coordinates, see figure 1

$\beta = \sqrt{M^2 - 1}$

$\gamma_{\pm}$ mass density of plate

$\lambda = \frac{2qa^3}{\beta D_+}$

ρ mass density of air

ω circular frequency

$$\Omega_{\pm}{}^2 = \frac{\omega^2 a^4 \gamma_{\pm} h_{\pm}}{D_{\pm}}$$

+,- subscripts refer to upper and lower plate, respectively

ANALYSIS

The equilibrium equations and appropriate boundary conditions are

$$D_+ \nabla^4 w_+ + N_{x+} \frac{\partial^2 w_+}{\partial x^2} + N_{y+} \frac{\partial^2 w_+}{\partial y^2} + \gamma_+ h_+ \frac{\partial^2 w_+}{\partial t^2} + k(w_+ - w_-) = l(x,y,t) \tag{1}$$

$$D_- \nabla^4 w_- + N_{x-} \frac{\partial^2 w_-}{\partial x^2} + N_{y-} \frac{\partial^2 w_-}{\partial y^2} + \gamma_- h_- \frac{\partial^2 w_-}{\partial t^2} + k(w_- - w_+) = 0 \tag{2}$$

$$\left.\begin{aligned} &w_{\pm}(x,0,t) = w_{\pm}(x,b,t) = w_{\pm}(0,y,t) = w_{\pm}(a,y,t) = 0 \\ &\frac{\partial^2 w_{\pm}}{\partial y^2}(x,0,t) = \frac{\partial^2 w_{\pm}}{\partial y^2}(x,b,t) = \frac{\partial^2 w_{\pm}}{\partial x^2}(0,y,t) = \frac{\partial^2 w_{\pm}}{\partial x^2}(a,y,t) = 0 \end{aligned}\right\} \tag{3}$$

where $l(x,y,t)$ is the lateral load per unit area due to aerodynamic pressure. For static strip theory the lateral load is given by the simple Ackeret value $l(x,y,t) = -\frac{2q}{\beta}\frac{\partial w_+}{\partial x}$.

A two-term Galerkin solution is pursued. Solutions which satisfy the boundary conditions for simply supported edges are assumed as follows:

$$w_{\pm}(x,y,t) = \left[C_{11\pm} \sin\left(\frac{\pi x}{a}\right)\sin\left(\frac{\pi y}{b}\right) + C_{21\pm} \sin\left(\frac{2\pi x}{a}\right)\sin\left(\frac{\pi y}{b}\right)\right] e^{i\omega t} \tag{4}$$

$$\begin{vmatrix} 1 - A_+ - B_+ + S_+ - \dfrac{S_+S_-}{1 - A_- - B_- + S_-} & -\dfrac{8}{3}\dfrac{\lambda}{\pi^4} \\ \dfrac{8}{3}\dfrac{\lambda}{\pi^4} & 16 - 4A_+ - B_+ + S_+ - \dfrac{S_+S_-}{16 - 4A_- - B_- + S_-} \end{vmatrix} = 0 \quad (5)$$

reduce to 6 inches and
insert on page 4

The frequency ω is, in general, complex; however, attention is directed primarily to real values for which the motion is harmonic.

When equation (4) is substituted into equations (1) and (2) and the Galerkin procedure is used, the following equation is obtained:

$$\begin{vmatrix} 1 - A_+ - B_+ + S_+ - \dfrac{S_+S_-}{1 - A_- - B_- + S_-} & -\dfrac{8}{3}\dfrac{\lambda}{\pi^4} \\ \dfrac{8}{3}\dfrac{\lambda}{\pi^4} & 16 - 4A_+ - B_+ + S_+ - \dfrac{S_+S_-}{16 - 4A_- - B_- + S_-} \end{vmatrix} = 0 \qquad (5)$$

Flutter occurs with the coalescence of two natural frequencies as the dynamic pressure parameter λ increases (see ref. 1). The procedure is to solve equation (5) for λ and maximize the resulting expression with respect to the frequency to obtain a critical value of the dynamic pressure parameter λ_{cr}. In many cases more than one critical value exists corresponding to the coalescence of different pairs of modes, and it is necessary to seek the lowest critical value to define a flutter boundary.

In order to illustrate the general flutter characteristics exhibited by this configuration, calculations were made for the simplified case for which $h_+ = h_-$, $D_+ = D_-$, $R_{y\pm} = 0$, $\frac{a}{b} = 1$, and $S_+ = S_- = S$. Flutter boundaries were derived from equation (5) for several combinations of streamwise midplane loads in the two plates. It must be remembered that these boundaries are subject to the same limitations that are described in reference 1; in particular, the range of validity of the boundaries is limited by the buckling characteristics of the plates.

DISCUSSION

For a single flat isotropic plate, the flutter boundary as determined from a two-term Galerkin solution is a linear function of the midplane load in the streamwise direction. Due to the coupling of the motions of the two plates, however, the configuration analyzed herein exhibits entirely different boundaries. Peaks and valleys occur in the boundaries due to the fact that the system can be tuned by means of the midplane loads.

Figures 2 through 4 present flutter boundaries $\left(\lambda_{cr} \text{ vs. } R_x\right)$ for square plates having various combinations of midplane loads and a spring parameter of $S = 20$. At the present time realistic values of S are not clearly defined; the value chosen ($S = 20$) might be typical of a configuration with a very soft filler material. The flutter boundary for a single flat plate with the same physical properties as either the upper or the lower plate considered in the present analysis is also shown in each of the figures (see ref. 1).

Figure 2 is a plot of the boundary for the configuration when there is no load in the lower plate. This boundary becomes asymptotic to the single plate boundary for large negative values of R_x, i.e., large midplane tension, as do all of the boundaries considered herein.

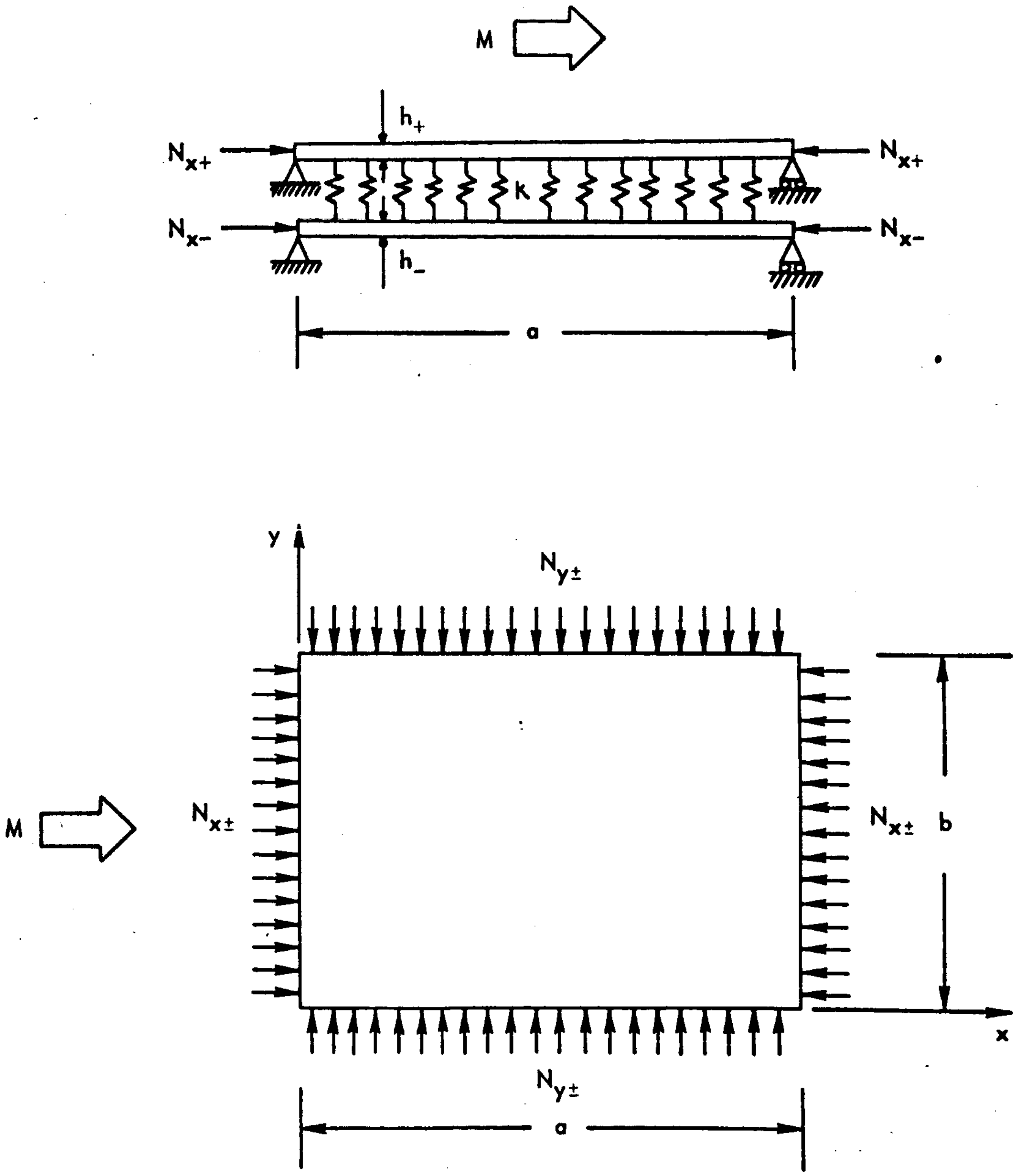
Figure 3 is a plot of the boundary when the midplane loads are the same in each plate. Here the tuning effect can be very significant since it is possible to have a zero flutter speed with a tensile load, and a peak exists which is much higher than the corresponding value for the single plate.

Figure 4 is a plot of the boundary when there is no load in the upper plate. This case is perhaps the most realistic combination of loading if the configuration is considered to be a micrometeoroid protection device. This boundary has characteristics very similar to the boundary in figure 2 except that here the tuning effect is more prevalent. In particular for streamwise tension, a condition which can be expected from bending loads on a space vehicle during launch, the elastically supported plate is more prone to flutter than the single plate alone.

The results of this analysis indicate that if a configuration similar to this one is utilized for applications where supersonic airflows are encountered, a very careful flutter analysis is in order to ensure that undesirable flutter characteristics are not present.

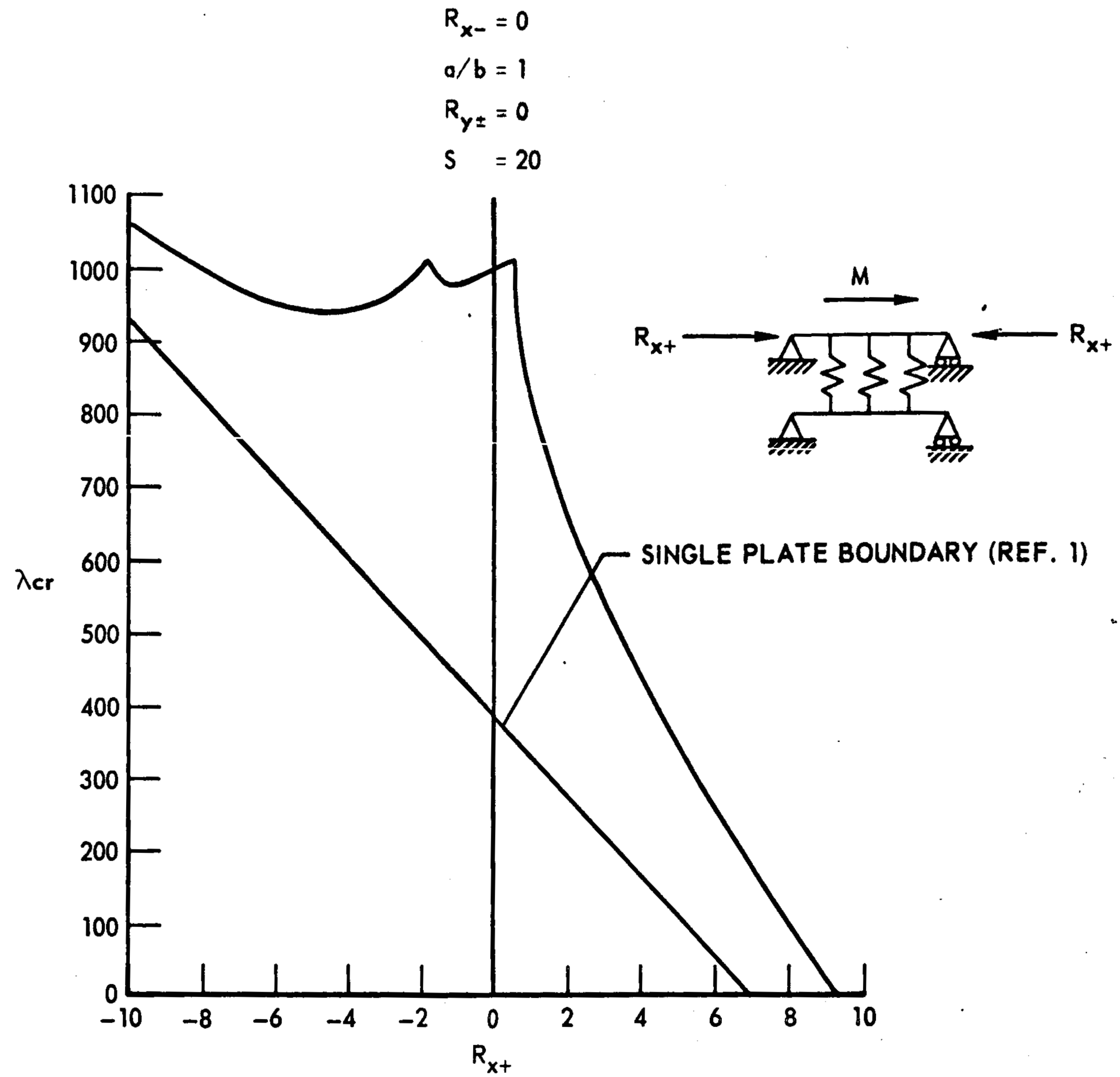
REFERENCE

1. Hedgepeth, J. M.: Flutter of Rectangular Simply Supported Panels at High Supersonic Speeds. Journal of the Aeronautical Sciences, vol. 24, no. 8, pp. 563-573, Aug. 1957.



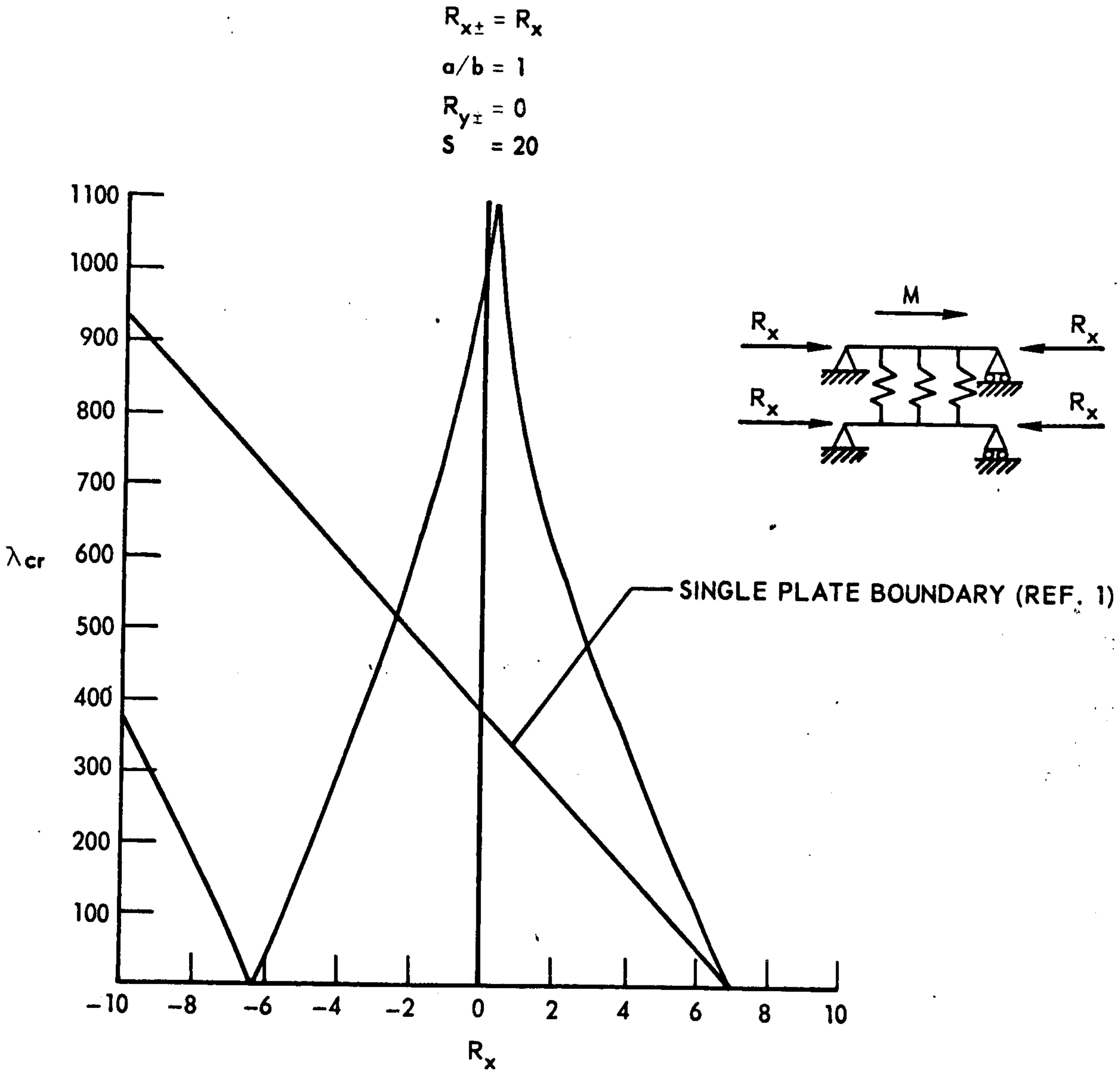
CONFIGURATION AND COORDINATE SYSTEM

Figure 1



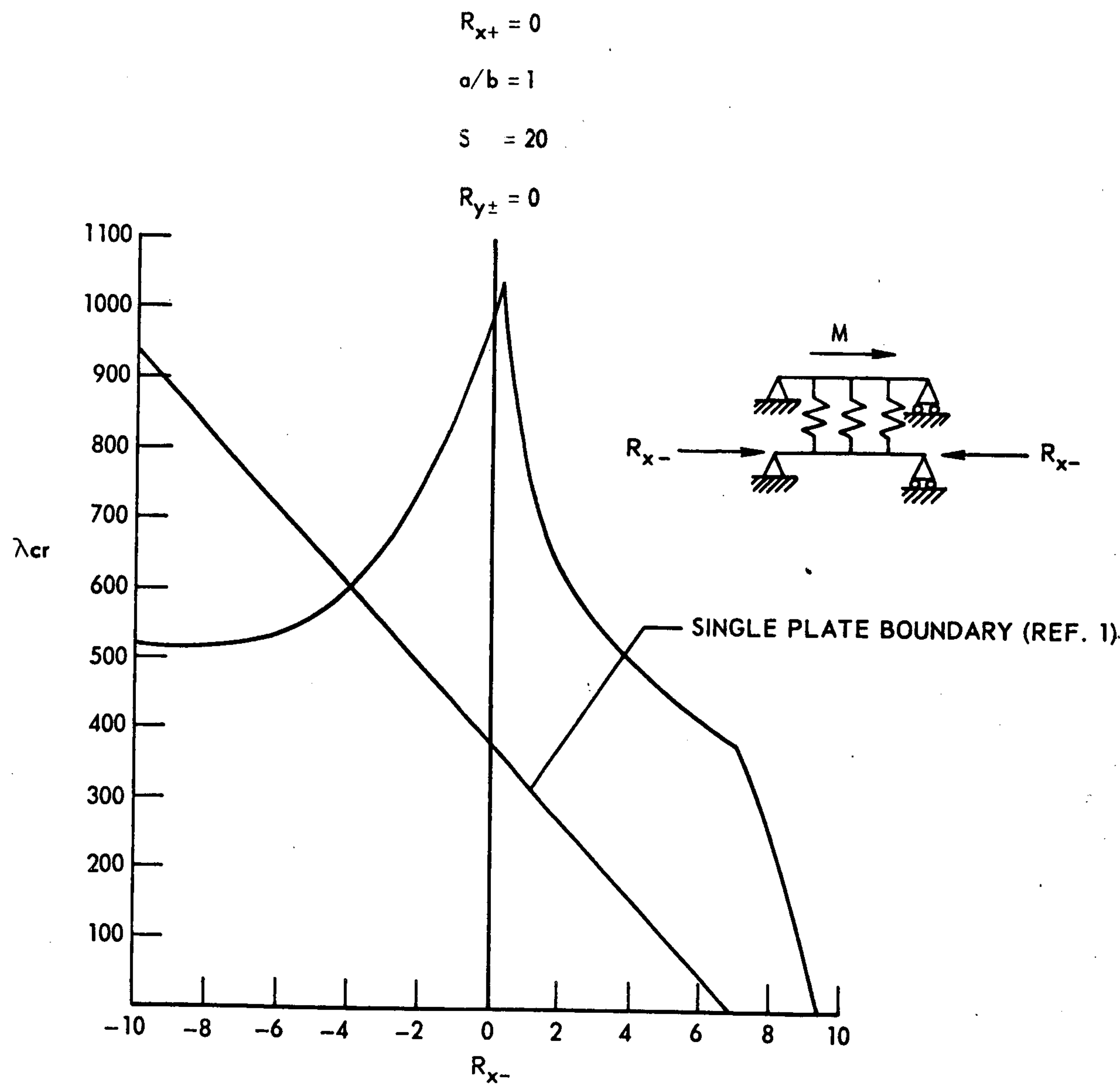
FLUTTER BOUNDARY FOR $R_{x-} = 0$

Figure 2



FLUTTER BOUNDARY FOR $R_{x+} = R_{x-} = R_x$

Figure 3



FLUTTER BOUNDARY FOR $R_{x+} = 0$

Figure 4